Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 156 (2016) 480 – 487

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Conference „Bridges in Danube Basin 2016“, BDB 2016

Design and calculation of the "Čadečka" highway bridge launching technology

István Szatmári[a,]*, Balázs Kövesdi[b]

[a]HEED Kft, Sasadi köz 1/b., Budapest, 1112, Hungary
[b]Budapest University of Technology and Economics, Department of Structural Engineering, Műegyetem rkp 3., Budapest, 1111, Hungary

Abstract

The authors had the opportunity to contribute in the erection process of the „Čadečka" highway bridge between September 2014 and June 2015. The tasks of the authors were to design and execute the launching process of the steel main girders together with the design of the launching technology and the static check of the superstructure in each launching phase. The specialty of the launching process consisted in the complex bridge geometry. In top view two third of the bridge is located in a right arch of a circle, one part is a transient arch, a short part is straight and the end of the bridge is located in a transient arch having opposite curvature than the another end. In side view the bridge has also a curved shape with an extreme point in the middle part. In addition to this complex geometry the relative level distance between the two main I-girders is not constant along the longitudinal axis, it follows the exact geometry of the carriageway. This complex geometry cannot be launched without continuous modification of the erected shape, which made the launching process difficult. The paper gives an overview on the specialties of this complicated design and calculation process.

Peer-review under responsibility of the organizing committee of BDB 2016

Keywords: bridge launching; Cadečka bridge; curved bridge, composite bridge.

1. Introduction and problem statement

A new highway bridge has been erected on the SK D3 highway between Svrčinovec-Skalite between 2014 - 2015. The bridge crosses the highway over a valley with 700 m width in a maximum ~60 meter height. Thus the height of the bridge piers are relatively large (max. 56 meters), the designers and the manufacturers decided by the launching manufacturing process. This manufacturing process eliminated or minimized the necessary work on the piers and made the largest safety and fastest way for the erection process. The only problem was that the bridge has a very

* Corresponding author. Tel.: +36-30-931-4797.
E-mail address: szatmari.istvanne9@upcmail.hu

Peer-review under responsibility of the organizing committee of BDB 2016
doi:10.1016/j.proeng.2016.08.324

special, complex geometry, as shown in Fig. 1, what is hard to launch using the usually used launching equipment and using the generally used launching technologies. Due to the complex launching process the designers decided to launch only the steel part of the composite bridge and the reinforced concrete deck is placed later, if the bridge reached its final location. In top view two third of the bridge is located in a right arch of a circle, one part is a transient arch and a short part is straight and the end of the bridge is located in a transient arch having opposite curvature than the another end. In side view the bridge has also a curved shape with an extreme point in the middle part. In addition to this complex geometry the relative distance between the two main I-girders is not constant along the longitudinal axis, it follows the exact geometry of the carriageway. The task of the authors was to design the launching technology and to execute the launching process of this complex geometry. This geometry cannot be launched without continuous modification of the erected shape which made the launching process quite difficult.

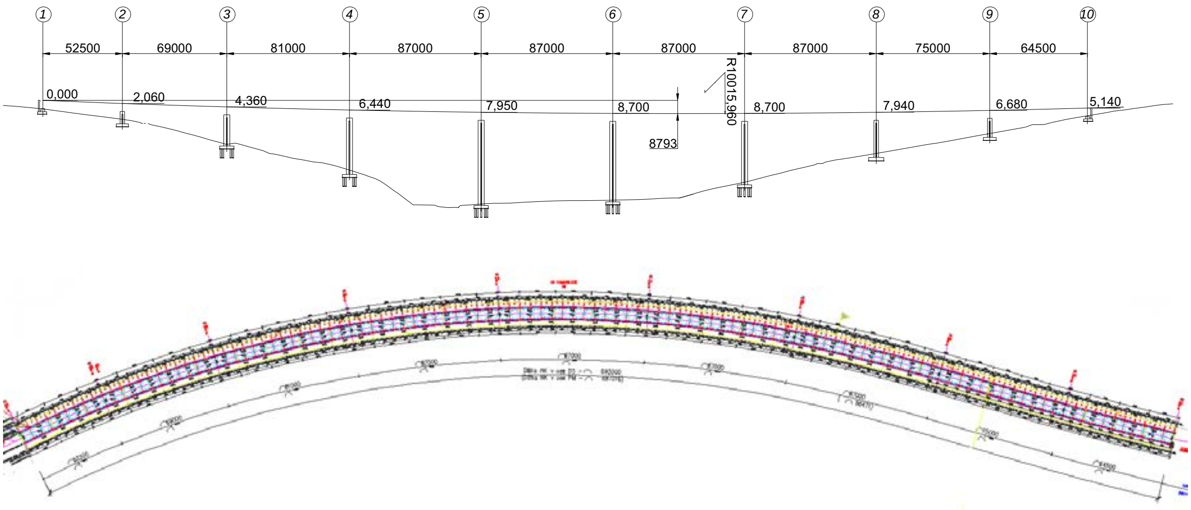

Fig. 1: Side view and top view of the “Čadečka” highway bridge.

First of all one part of the difficulties are in the static calculation of the launching process, because the continuous modification of the steel girder shape has to be taken into account. The modification of the shape in the steel girder gives additional normal and shear stresses to the main girder and it has also influence on the drive force. If the girder is stressed between the supports at the piers, the force which brings to move the bridge will increase and if the bridge is released from the supports, the drive force can decrease. To design the launching technology and the launching devices the drive force had to be determined with large accuracy, which needed a more complicated calculation as usual for bridges with simple geometry. On the other hand, difficulties are found in the design of the launching devices, because due to the large differences in the geometry all the launching devices had to be able to move and follow the geometrical changes of the bridge superstructure. This paper gives an overview on the specialties of this complicated design and calculation process and gives the way how the authors overcome of these difficulties and the bridge was erected without any significant problem in the launching process.

2. Description of the superstructure and the launching process

The currently erected “Čadečka” highway bridge is a composite girder bridge having 9 spans. The steel main girders are built using incremental launching technique and the reinforced concrete deck was placed on the steel girders at the final stage. The nominal span lengths are 52.5 + 69.0 + 81.0 + 4*87.0 + 75.9 + 64.5 m = 690 m. The general cross section of the bridge is presented in Fig. 2. The bridge was designed by the SHP (Brno) company and erected by the Promont s.r.o. (Krásno nad Kysucou) company. The superstructure contains two steel I-girders with longitudinal stiffeners and with transversal ribs. It contains a cross bracing system and two (upper and lower) wind bracing systems. The distance between the main girders is 6700 mm. The I-girders have asymmetric cross sections with a web depth of 4400 mm and web thickness of 14 mm in the main part of the bridge. The upper flange has a width of 900 mm with a thickness of 25 – 60 mm changing along the longitudinal axis. The lower flange has a width of 1200 mm with a thickness of 30 – 95 mm. The web plates are stiffened with three longitudinal stiffeners placed in an equal distances along the web depth and placed on the outer side of the web. The distances between the ribs and the truss cross girder systems are 3000 mm. The applied steel material is S420 in the main part of the bridge, however steel with S460 grade is also applied in the internal support regions.

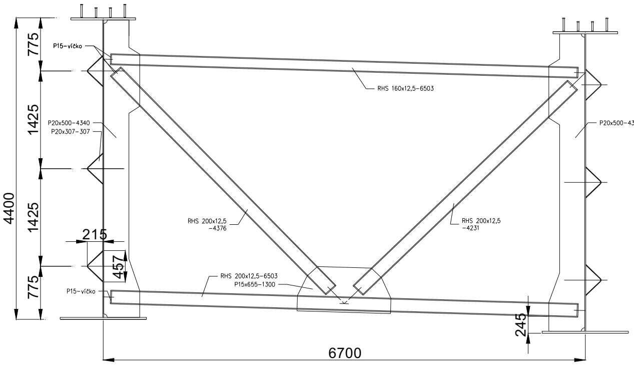

Fig. 2: General cross section of the “Čadečka” highway bridge.

The geometry of the bridge is quite complex. The top view of the bridge is located in a curvature of R=700 m between the piers 1-7. Between the piers 7-10 the curvature of the bridge changes continuously with a small straight part in the middle. The distance between the real bridge geometry and a circle (what could be launched without any additional deformations) is 23015 mm. The vertical view of the bridge is also a circle with a radius of R=10000 m. The lowest point is located between the piers 6-7, what is located with 8793 mm lower than the pier 1. The geometry of the superstructure can be seen in Fig. 3 under erection.

Fig. 3: Side view of the “Čadečka” highway bridge.

Thus the bridge has two dominantly different part from geometrical point of view, the authors and the designers decided to make the launching process from the two ends simultaneously. The firstly erected part was the structure between the piers 1-7, for which part is a circle from top view. The another part was between the piers 7-10 with its double curvature. For both parts a launching truss has been designed and erected with a nominal length of 48.0 m to reduce the negative bending moments at the cantilever stages. The global geometry of the launching truss can be seen in Fig. 4. The truss girder was manufactured from 4 segments to be able to follow the curvature of the launching path. The launching truss has two main truss girders connected by cross girder system. The sections of the truss are welded sections using S355 steel material.

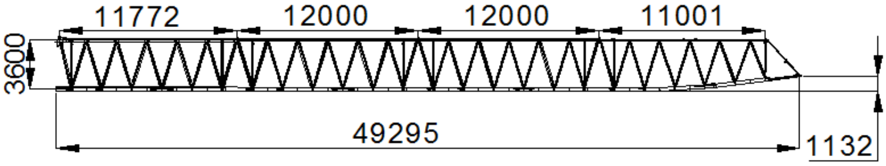

Fig. 4: Geometry of the launching truss.

Two erection shops with a length of ~25.0-30.0 m are built at both ends of the valley. The steel main girder segments with a ~12.0 m length are transported to the site where all the necessary welding and the launching process needed only 3 days pro segments. Therefore the transportation, assembly and launching of a 12 m long segment could be erected in a 3-4 day period. The launching process from the two sides are presented in Fig. 5.

Fig. 5: Launching process of the "Čadečka" highway bridge.

The superstructure was supported at discrete points on the erection shop and on the piers. Launching devices are placed on the top of all the piers, which ensured movable support to the superstructure, however the movement of the bridge was only applied at the end supports. The launching device ensured a 2 m long continuous support to the bridge ensuring uniformly distributed loads along the launching device. The main problems were caused by the transversal support of the bridge. The location of the structure and the erection period (~8-12 month) resulted that the design value of the wind load had an intensity of 2.5 kN/m^2. This huge wind load and the additional transversal forces coming from the deformation of the bridge to the loading path requested very strong lateral supports, which are manufactured from steel structure and which are placed on the piers. The longitudinal movement of the superstructure was made using hydraulic jacks. It has to be mentioned thus the bridge was launched from the upper points of the launching path and moved to downhill direction, therefore additional braking system is also implemented in the launching device.

3. Numerical modelling of the launching process and design of the superstructure

The aims of the static calculation are to perform the strength and stability check of the superstructure and to determine the maximum horizontal and vertical reaction forces acting on the launching devices. The static calculations are performed within the following three steps:

- Launching simulation was performed to check the possible overloading of the launching devices as well as the superstructure of the bridge. The launching simulation was performed step-by-step within 1 m increment. In all the modelled launching phases the static check of bridge structures has been performed.
- The load carrying capacity of the launching truss has been also checked and the position of the launching

truss ends are determined to check the position of the bridge by reaching the piers.

- In case of all the launching steps the horizontal and vertical reaction forces are determined to check and eliminate the possible overloading of the launching devices. Within this step the necessary drive force is also determined to check the requested capacity of the hydraulic jack.

The bridge superstructure is modelled by a full shell model using Ansys 14.5 [1]. The bracing system (cross bracing and wind bracing) and the launching truss was modelled using beam elements. The piers are modelled by concentrated supports if the support reactions are determined and by distributed supports, if the patch loading resistance and the M-V-F interaction of the main girder was calculated. To model the lateral supports, springs are applied, where the spring coefficients are calculated from the lateral stiffness of the piers and the launching device. The applied finite element mesh is a relative fine mesh having the maximum element size of 100 mm. The global geometry of the model and several details of the main girders and the launching truss can be seen in Figs. 6-7.

Fig. 6: Global numerical model of the "Čadečka" highway bridge.

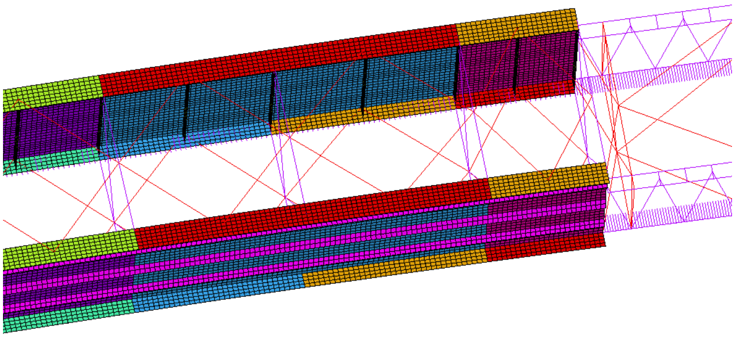

Fig. 7: Details of the numerical model.

The applied loads during the launching process are the self-weight, wind, temperature and the deformation of the structure coming from the launching path. The intensity of the wind load was taken 2.75 kN/m^2 on one side of the cross section (compression force) and 0,55 kN/m^2 on the another side (tension force). The wind load acting on the launching truss was set to 2,55 kN/m^2 on both truss girders. During the numerical calculations both wind directions are investigated and the ultimate directions from point of view of the support reactions and the internal forces in the superstructure are selected for all the launching phases. Ununiform temperature loads are also defined on the superstructure with the values of +15/-5°C, representing the design temperature load in the erection period. From the differences between the geometry of the erected shape of the steel main girder and the launching path additional displacement loads are defined in the model at the actual locations of the piers. The necessary values of the displacements loads at each piers are recalculated for all the analysed launching phases and its values are automatically updated in the numerical model. These displacement loads ensured the consideration of the differences between the bridge geometry and the loading path, what had a significant role in the calculation process. The stresses and the deformations due to the self-weight, wind, temperature and displacement loads are calculated in the characteristic load case combination. The results of the launching simulation are the influence lines for the vertical and horizontal support reaction forces and the extreme values of the stresses in the superstructure. One example is presented for the support reaction distributions at each piers (Fig. 8) and one for the stress extreme values in the steel I-girder (Fig. 9). The support reaction diagrams has an alternating tendency, which comes from the effect of the wind load. The increasing tendencies of the support reactions can be clearly observed on the diagram if the structure reached a pier. The aim of the calculation was to check that the maximum reaction force does not overcome on the maximum allowable reaction force (3000 kN), what was the design resistance level of the launching device. Similar reaction force influence lines are produced for the horizontal reaction forces as well and its maximum values are also checked.

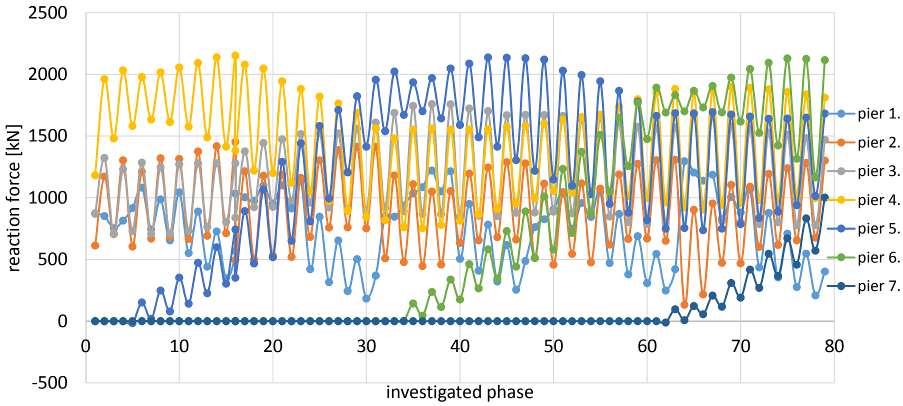

Fig. 8: Calculated vertical reaction forces at piers 1-7.

If has to be mentioned, that until the determination of the vertical support reaction forces are relatively easy, the calculation of the horizontal reaction forces are more complicated. Vertical reaction forces have three different origins, (i) wind load, (ii) curvature of the bridge structure and (iii) drive force during launching. Thus the drive force is acting only in case of moving the structure and in case of large wind, there are no launching, these three effects cannot occur at the same time. Therefore these values should be calculated separately and added considering the possible real loading situations. The determination of the drive force needed a special model applying week springs at the location of the piers and simulating the launching of the structure. The results showed that the maximum value of the drive force is significantly smaller than the reaction forces coming from the wind load effect, therefore the wind load was the dominant effect and resulted the maximum vertical support reaction on the launching device.

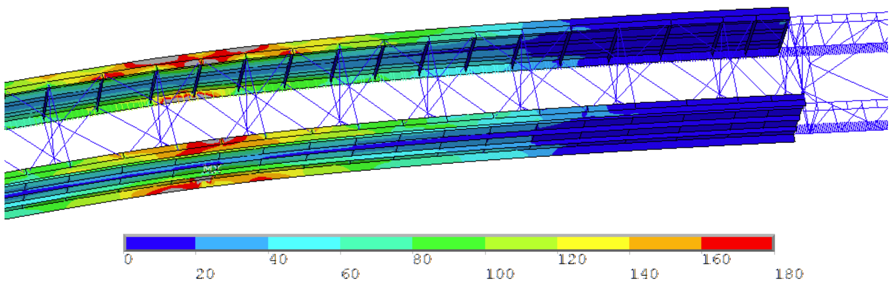

Fig. 9: Calculated vertical reaction forces at piers 1-7.

The static calculation of the bridge structure was also performed in all the launching steps. The maximum tension and compression stresses and the accompanying reaction forces are determined and the stability check of the longitudinally stiffened girder was performed according to the rules of the EN1993-1-5 [2] extended by an M-V-F interaction check [3] according to additional numerical calculations.

4. Analytical and numerical calculation of the drive force

During the launching process the necessary drive force was measured continuously. The results of these measurements highlighted that the correct determination of the drive force is a safety issue. The bridge between the piers 1-7 is located in a downhill with a slope of 4,5%, and this slope is reduced to 2% between the piers of 7-10. The theoretical minimum sliding coefficient at the launching devices is 3-4%, but the measurements showed, that sometimes the bridge could be launched with almost zero drive force, and the application of a braking system was necessary. The reason of this phenomenon is the following. The actual drive force can be calculated by Eq. (1).

$$V = V_F + V_E + V_K \tag{1}$$

where: V_F is the force coming from friction,
V_E is the force coming from the change of the potential energy of the structure,
V_K is the force needed for acceleration of the structure.

The value of V_F can be calculated from the friction coefficient and the sum of the reaction forces at each stage. It has to be mentioned that from the reaction forces not only the vertical forces, but the horizontal reaction forces has to be taken into consideration. The friction coefficient depends on the launching device, the applied materials and oils. In case of the currently used launching equipment the friction coefficient regarding a non-moving structure is equal by 0.06-0.19, which value reduces to 0.02 – 0.05 for the moving situation. The friction coefficients of the applied materials was significantly time-dependent coming from the visco-plastic material properties. The value of V_E can be calculated by Eq. (2).

$$\Pi = \frac{1}{2} \cdot \int_{S_o} EI_s \cdot \rho^2 \cdot ds - \int_{S_o} g_s \cdot y \cdot ds \tag{2}$$

If the structure is moved from the location x_0 to the location x_1 the potential energy will be changed, and this change can be characterized by the work of the drive force, as shown in Eq. (3).

$$\Pi_{(x_1)} - \Pi_{(x_0)} = V_E \cdot (x_1 - x_0) \quad \text{where:} \quad V_E = \frac{d\Pi_{(x)}}{dx} \tag{3}$$

If the superstructure would be rigid (ρ=0) and the launching path would be a straight line with a slope of (m), the change in the potential energy could be expressed by Eqs. (4) - (5).

$$\Pi = -\int_{S_o} g_s \cdot y \cdot ds = -G \cdot m \cdot x \qquad V_E = \frac{d\Pi_{(x)}}{dx} = -G \cdot m \tag{4}$$

If the superstructure is elastic and the launching path is not a straight line the actual values of the integrals has to be calculated. In our case the calculations showed, that the negative value of V_E can reach 1.5-2% of the total reaction force, which can explain the observations and the degradation of the drive force in case of the real launching process. The value of V_K compared to the another two components by the current launching velocities is negligible. However the launching device should be prepared to be able to stop the structure within a short distance, which requires to carry a braking force which value is comparable to the value of the drive force. In the followings an example is introduced to calculate the drive force coming from the change of the potential energy. The bridge is represented by a HEA400 profile with a length of 40 m. This girder will be launched through a span of 30 m from the position A to the position B, as shown in Fig. 10. The girder has the necessary load carrying capacity, and the stability failure is not considered in the example. The erected shape of the girder has a parabolic shape with 200 mm superelevation. The value of the V_E is calculated considering the real erected shape and a straight line as a shape of the bridge (model shape). The results of the calculation are presented in Fig. 11. The change of the drive force can be observed on the diagram step-by-step and based on the results the following conclusions can be drawn:

- the drive force has a negative value with an intensity of 1,5-2,0 %, therefore braking is needed;
- the geometry of the erected shape has significant influence on the drive force;
- the value of the drive force is also influenced by the fact, that the supports are not always active.

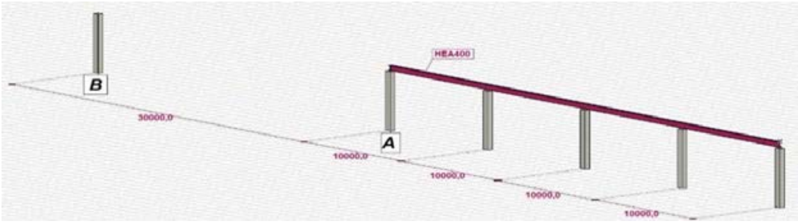

Fig. 10: Muster example for the calculation of the drive force.

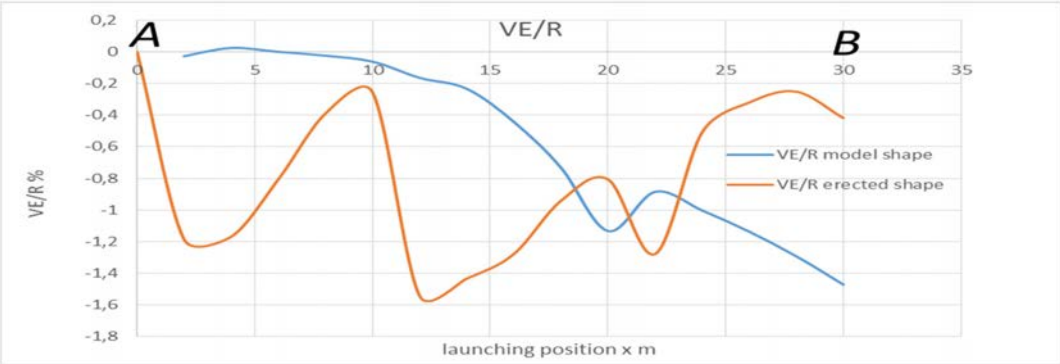

Fig. 11: Calculated drive forces compared to the reaction forces.

5. Summary

The current paper gives a short report about the launching process and launching technology of the “Čadečka” highway bridge. The paper introduces the executed calculations and presents the specialties of the launching technology of this very complex bridge structure. The paper draw the attention on the importance of the correct determination method of the drive force and its consequences in the design of the launching technology.

Acknowledgement

We would like to commemorate the tragically deceased General Director of Ingsteel s.r.o. dr. Anton Bezak. The project described above was based on his decision and effectuation, taking both the responsibility and risk implied in the solution and performance of a special work like that. In the course of our collaboration we were honoured to feel his trust, confidence and help even in critical situations. His memory as a real friend will live on in our hearts. We wish to express our gratitude to Professor dr. Agócs Zoltán for his idea of the applying of the launching method. We enjoyed his precious cooperation throughout the whole construction process. The project could not have been realized without his support. We take the chance to express our thanks to our collegues at Ingsteel s.r.ro. (Bratislava) for their help and contribution in the planning and implementation of the project. The successful construction work was accomplished with the cooperation of Promont s.r.o. (Krasno nad Kysucou) staff, thanks them for that. Also we are grateful to all the people who contributed in the realization of the successful accomplishment of the project.

References

[1] ANSYS® v14.5, Canonsburg, Pennsylvania, USA.

[2] EN 1993-1-5 2006: EUROCODE 3- Design of steel structures Part 1-5: Plated structural elements, 2006.

[3] B. Braun: Stability of steel plates under combined loading. PhD thesis, No. 2010-3, Institute for Structural Design, Universität Stuttgart, 2010.